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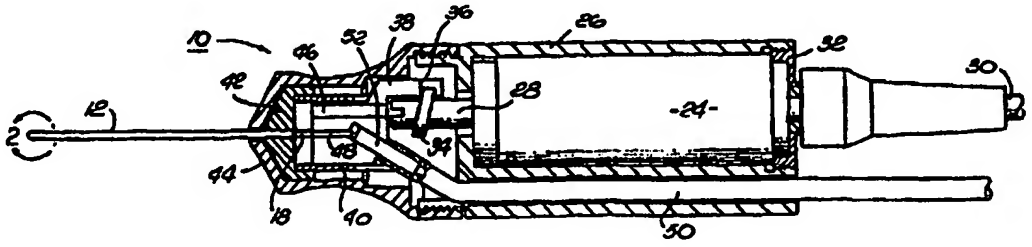

(57) Abstract

This invention is a surgical cutting system. The cutting system includes a cutter (10) which has an inner sleeve (18) that moves adjacent to an aspiration port of an outer sleeve (12). The inner sleeve is coupled to a source of vacuum that pulls tissue into the outer port (14) when the inner sleeve is moved away from the port. The inner sleeve then moves across the outer port and severs the tissue in a guillotine fashion. The inner sleeve may have circumferential slits (112, 130) that allows the sleeve to bend into the aspiration port during the cutting stroke of the cutter. The cutter includes a motor (24) which creates an oscillating translational movement of the sleeve. The motor speed can be controlled by a foot pedal and a controller that automatically varies the electrical power provided to the motor to compensate for different loads on the cutter. The cutter may contain electrodes that are connected to an electrical generator. The generator provides electrical energy to the cutter and adjoining tissue. A surgeon can thus both cut and cauterize with the same device.

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AN APPARATUS AND METHOD FOR PERFORMING OPHTHALMIC PROCEDURES

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The present invention relates to a surgical system for cutting tissue.

2. DESCRIPTION OF RELATED ART

There are many surgical procedures that require the cutting and aspiration of tissue. For example, in a retina re-attachment procedure the surrounding vitreo tissue must be removed before the retina is repaired. The cutting device must be delicate enough to remove the tissue without further damaging the retina. Prior art ophthalmic cutting devices include an inner sleeve that moves relative to an outer port of an outer sleeve. The sleeves are coupled to a vacuum system which pulls tissue into the outer port when the inner sleeve moves away from the port. The inner sleeve then moves in a reverse direction past the outer port to sever the tissue in a guillotine fashion. The vacuum system draws the severed tissue away from the outer port so that the process can be repeated.

The inner sleeve is driven by a motor located within a hand piece that is held by the surgeon. The inner sleeve is typically coupled to the motor by a rotating lever mechanism. Rotating lever mechanisms of the prior art are relatively large and complex. Additionally, the stroke and duty

cycle of the inner sleeve is fixed for each device. It would be desirable to provide a surgical guillotine cutter that is inexpensive to produce, small in size and would allow a surgeon to vary the stroke and duty cycle of the inner cutter.

Guillotine cutters are typically provided with a control system that allows the surgeon to vary the vacuum pressure of the aspiration line. U.S. Patent Nos. 4,395,258; 4,493,698; 4,706,687 and 4,838,281 issued to Wang et al. and Rogers et al., respectively, disclose systems for controlling the vacuum pressure of a guillotine cutter. The Wang/Rogers systems include a solenoid actuated valve that is coupled to the hand piece and controls the flow of fluid in the aspiration system. The position of the valve and the corresponding vacuum of the system is controlled by an input signal provided to the solenoid by a control circuit. The input signal is typically the summation of a feedback signal and a control signal that is generated by a potentiometer. The feedback signal corresponds to the actual vacuum pressure measured in the system. The potentiometer is typically a foot pedal that is manipulated by the surgeon.

The surgeon controls the vacuum pressure by depressing the foot pedal and varying the amount of air flow through the solenoid control valve. Because of the inertia within the system, there is typically a lag between the input command of the surgeon and the actual variation of vacuum pressure at the tip of the cutter. It would be desirable to provide a vacuum control system that has a more rapid response time than systems of the prior art.

Additionally, prior art guillotine cutters typically do not have many control functions, or safety features to prevent inadvertent damage to the eye. For example, prior art systems do not automatically compensate for variations in the load on the cutter. The surgeon must observe a reduction in cutting rate and then manipulate the cutter and the vacuum pressure to overcome the increased load. Additionally, with a prior art cutter, if the cutter ceases to operate while the vacuum pressure is applied to the system, the tissue may be pulled into the aspiration port of the outer sleeve. Such an event may damage the eye. It would be desirable to provide a guillotine cutter which has a number of control functions and safety features.

Cutting tissue sometimes causes undesirable bleeding which must be coagulated. Coagulation can be performed with an electro-cautery device. To coagulate the tissue the cutter is removed and an electro-cautery device is inserted into the patient. To continue cutting, the electro-cautery device must be removed to allow re-insertion of the cutter. Such a procedure is time consuming and may reduce the safety of the procedure. It would be desirable to provide a cutter that can also cauterize tissue.

SUMMARY OF THE INVENTION

The present invention is a surgical cutting system. The cutting system includes a cutter which has an inner sleeve that moves adjacent to an aspiration port of an outer sleeve. The inner sleeve is coupled to a source of vacuum that pulls tissue into the outer port when the inner sleeve is moved away from the port. The inner sleeve

then moves across the outer port and severs the tissue in a guillotine fashion. The inner sleeve may have a circumferential slit(s) that allows the sleeve to bend into the aspiration port during the cutting stroke of the cutter.

The cutter includes a motor which creates an oscillating translational movement of the sleeve. The motor speed can be controlled by a foot pedal and a controller that automatically varies the electrical power provided to the motor to compensate for different loads on the cutter. The cutter may contain electrodes that are connected to an electrical generator. The generator provides electrical energy to the cutter and adjoining tissue. A surgeon can thus both cut and cauterize with the same device.

The inner sleeve is coupled to an aspiration line that pulls the severed tissue out of the cutter. The level of the aspiration vacuum pressure can be controlled by varying the speed of the motor and the movement of the inner sleeve, or by the rotation of an external rotary valve. The aspiration pressure may be created by a vacuum pump which has electronically controlled intake and exhaust valves. A controller may vary the timing of the valves to change and control the vacuum pressure. The vacuum pressure may also be created by a plurality of vacuum pumps that are sequentially activated to vary the flowrate of the aspiration fluid. Additionally, the controller can automatically move the inner sleeve to close the aspiration port when the cutter is de-activated. The closed aspiration port prevents tissue from being pulled into the cutter.

BRIEF DESCRIPTION OF THE DRAWINGS

The objects and advantages of the present invention will become more readily apparent to those ordinarily skilled in the art after reviewing the following detailed description and accompanying drawings, wherein:

Figure 1 is a cross-sectional view of surgical guillotine cutter of the present invention;

Figure 2 is an enlarged cross-sectional view of the tip of the cutter;

Figure 3 is an enlarged view similar to Fig. 2 showing tissue being drawn into an outer port of the cutter;

Figure 4 is a an enlarged view similar to Fig. 2 showing an inner sleeve severing the tissue drawn into the outer port;

Figure 5 is a schematic of a vacuum control system for the cutter;

Figure 6 is a side cross-sectional view of an alternate cutter;

Figure 7 is a side cross-sectional view of an alternate cutter;

Figure 8 is a perspective view of a cutter system of the present invention which has an electrical generator coupled to a cutter;

Figure 9 is an enlarged view of a cutter tip which functions as an electrode;

Figure 10 is a schematic of a system for controlling the motor speed of a cutter;

Figure 11 is a schematic of a system that terminates the vacuum supply when the cutter no longer cuts;

Figure 12 is a schematic of a system that can terminate a flow of irrigation fluid;

Figure 13 is a schematic of a system which contains a plurality of vacuum pumps;

Figure 14 is a schematic of a system that contains a vacuum pressure pump and a positive pressure pump;

Figure 15 is a schematic of a system that contains a pump which has electronically controlled intake and exhaust valves;

Figure 16 is a schematic of a rotary valve that controls the flow of aspiration fluid;

Figure 17 is a schematic showing a solenoid driven guillotine cutter;

Figure 18 is a side view of a bent tip;

Figure 19 is a side view of a tip that has a plurality of aspiration ports;

Figure 20 is side view showing a transmitter that tracks the location of a cutter within tissue.

DETAILED DESCRIPTION OF THE INVENTION

Referring to the drawings more particularly by reference numbers, Figures 1 and 2 show a surgical guillotine cutter 10 of the present invention. The cutter 10 is used to remove and aspirate tissue. For example, the cutter 10 can be used to remove intraocular tissue during an ophthalmic procedure to re-attach a retina of an eye. Although use in an ophthalmic procedure is described, it is to be understood that the cutter 10 can be used to cut and aspirate other tissue, such as removing polyps, fibroids and other vascularized human tissue.

Referring to Fig. 2, the cutter 10 includes an outer sleeve 12 that has an outer port 14. The outer port 14 is in fluid communication with an inner channel 16 of the sleeve 12. Located within the inner channel 16 of the outer sleeve 12 is an inner sleeve 18. The inner sleeve 18 has an inner

channel 20 that is in fluid communication with an aspiration system. The aspiration system creates a vacuum pressure that pulls tissue into the outer port 14 when the inner sleeve 18 is located away from the port 14. The inner sleeve 18 moves within the inner channel 16 of the outer sleeve 12 to cut tissue that is pulled into the outer port 14 by the aspiration system.

Figures 3 and 4 show tissue 22 that is cut by the cutter 10. The inner sleeve 18 is initially moved away from the outer port 14 and the vacuum pressure pulls tissue 22 into the port 14 and the inner channel 16. The inner sleeve 18 then moves toward the outer port 14 and severs the tissue 22 within the inner channel 16. The severed tissue is pulled through the inner channel 20 of the inner sleeve 18 by an aspiration system. The inner sleeve 18 then moves away from the outer port 14 wherein the cutting process is repeated.

The movement of the inner sleeve 18 also controls the flow of fluid through the outer port 14 and into the aspiration system. Increasing the cutting speed decreases the flow rate and vice versa. The flow of fluid through the opening 14 may vary the vacuum pressure within the aspiration system. In addition to varying the cutting speed the surgeon may also vary the vacuum pressure by changing the speed of the motor and the flow of fluid through the opening 14. The cutting device 10 of the present invention can thus control the vacuum pressure within the aspiration system by controlling the oscillation speed of the inner sleeve 14.

Referring to Figure 1, the cutter 10 includes a motor 24 that is located within a hand piece 26. Extending from an end of the motor 24 is a

rotating output shaft 28. The motor 24 is preferably an electrical device that is coupled to an external power source by wires 30 that are attached to a plug 32 screwed into the hand piece 26. The rotational speed of the output shaft 28 is a function of the amplitude of an input signal that is provided by wires 30. Although an electrical motor is described, it is to be understood that the motor may be a pneumatic device.

The cutter 10 has a wobble plate 34 that is attached to the output shaft 28 of the motor 24. The wobble plate 34 is located within a groove 36 of a slider 38. The slider 38 is attached to the inner sleeve 18. Rotation of the output shaft 28 spins the wobble plate 34, which induces an oscillating translational movement of both the slider 38 and the inner sleeve 18. The motor 24 and wobble plate 34 move the inner sleeve 18 in an oscillating manner to cut tissue as shown in Figs. 3 and 4.

The slider 38 moves within a bearing sleeve 40 that is captured by an inner cap 42 and an outer cap 44 of the cutter 10. The outer cap 44 is screwed onto the hand piece 26. The slider 38 may have an aperture 46 that extends therethrough to allow air to flow out of the area between the slider 38 and the inner cap 42. The aperture 46 prevents the formation of a back pressure that may impede the movement of the slider 38. The slider 38 further has a channel 48 that is coupled to an aspiration line 50 by a tube 52. The channel 48 provides fluid communication between the aspiration line 50 and the inner channel 20 of the inner sleeve 18.

The stroke and the duty cycle of the inner sleeve 18 are related to the cam angle and profile of the wobble plate 34. The stroke and/or duty cycle can be varied by removing the cap 44 and replacing the wobble plate 34 with a new part which has a different cam angle and/or profile. The present invention thus allows a surgeon to readily change the duty cycle and stroke of the device 10.

Figure 5 shows a system 60 for controlling the vacuum pressure within the cutter 10. The system includes a positive pressure source 62 which creates a positive pressure. The output of the positive pressure source 62 may be regulated by a regulator 64. The regulator 64 may be coupled to a shut-off valve 66 that can de-couple the source 62 from the remaining portion of the system 60.

The positive pressure created by the pump 62 is converted into a negative vacuum pressure by a converter 68. The converter 68 may be a venturi pump that is relatively linear in operation. The system 60 may have a reservoir 70 that is coupled to the converter 68 and the aspiration line 50 of the cutter 10. The converter 68 creates a vacuum pressure within the aspiration line 50 of the cutter 10, to pull the tissue into the outer port 14 of the outer sleeve 12, and to aspirate the severed tissue.

The system 60 includes a potentiometer 72 which provides a variable input signal to the motor 24 of the cutter 10. The potentiometer 72 is typically a foot pedal which can be manipulated by the surgeon to vary the input signal and the speed of the motor 24. Varying the speed of the motor 24 changes the oscillation frequency of the inner sleeve 18, the flow of fluid through the

outer port 14 and the vacuum pressure within the system. The surgeon can therefore control the flow of fluid through the aspiration system by manipulating the foot pedal 72 and varying the motor speed of the cutter 10.

The potentiometer 72 may be coupled to the motor by a control circuit 74. The control circuit 74 is coupled to the output of a differential amplifier 76. One input of the differential amplifier 76 is coupled to a transducer 78 that senses the vacuum pressure within the system. The transducer 78 provides an output signal that corresponds to the magnitude of the vacuum pressure. The other input of the differential amplifier 76 may be connected to a vacuum limit control 80 which limits the level of the vacuum pressure. The differential amplifier 76 and transducer 78 provide a closed loop feedback signal for the aspiration system.

The control circuit 74 compares the feedback signal provided by the differential amplifier 76 with the control signal provided by the potentiometer 72 and generates the input signal for the aspiration system. The control circuit 74 typically adds, the difference between the feedback signal and the control signal from the foot pedal, to the control signal. The control circuit 74 may include a differential amplifier and adder connected as shown in U. S. Patent No. 4,838,281, which is hereby incorporated by reference. The system 60 may include a variable cut rate limit control circuit 82 that limits the amplitude of the motor input signal and allows the surgeon to control the minimum and maximum cutting speed of the cutter 10.

The system 60 may have a first solenoid exhaust valve 84 that bleeds off the vacuum line to decrease the magnitude of the vacuum pressure. The valve 84 may be coupled to the control circuit 74 to lower the magnitude of the vacuum pressure when the actual pressure level exceeds a desired pressure level. The system 60 may also have a second solenoid exhaust valve 86 that quickly returns the system to atmospheric pressure. The shut-off valve 66 and second exhaust valve 86 can be coupled to the potentiometer 72 so that the shut-off valve 66 is closed and the exhaust valve 86 is opened when the surgeon releases the foot pedal 72 and moves the potentiometer to an off position. Returning the system to atmospheric pressure prevents a sudden vacuum surge when the surgeon again utilizes the cutter 10 at a surgical site.

The system 10 may also have an off detect circuit 88 which drives the motor 24 and moves the inner sleeve 18 to close the outer port 14 when the surgeon releases the foot pedal 72. Closing the outer port 14 prevents the residual vacuum of the system from pulling in tissue when the cutter 10 has been inactivated. The detect circuit 88 may drive one of the motor coils when the foot pedal is released to move the inner sleeve 18 to an extended position that closes the outer port 14.

In operation, a surgeon may insert the outer sleeve 12 into an eye to perform an ophthalmic procedure. The surgeon may remove intraocular tissue by depressing the foot pedal 72 and initiating the cutting action of the cutter 10. The cutting speed and fluid flow can be varied by manipulating the foot pedal 72 and varying the

motor speed of the cutter. Valving the vacuum pressure at the outer port 14 of the cutter provides an almost instantaneous response time for varying the fluid flow at the surgical site. Releasing the foot pedal 72 closes the shut-off valve 66 and opens the exhaust valve 88 to return the system 60 to atmospheric pressure.

While certain exemplary embodiments have been described and shown in the accompanying drawings, it is to be understood that such embodiments are merely illustrative of and not restrictive on the broad invention, and that this invention not be limited to the specific constructions and arrangements shown and described, since various other modifications may occur to those ordinarily skilled in the art.

By way of example, the aspiration line 50 and/or reservoir 70 may be directly coupled to the intake port of a linear pump. The potentiometer 72 and/or control circuit 74 may provide an input signal to control the output of the linear pump and the vacuum pressure within system. The linear pump may be a device sold by Medo of Woodale, Illinois under the part designation VP0660. In this embodiment, the vacuum pressure may also be further regulated by controlling the motor speed of the cutter 10.

Although a control circuit 74 is shown and described, it is to be understood that the foot pedal 72 can be connected directly to the motor 24 without a feedback input. Additionally, although a foot pedal 72 is shown and described, it is to be understood that the motor 24 could be controlled by a handpiece or other input device.

Figure 6 shows an alternate embodiment of a cutter 100. The cutter 100 includes an outer

sleeve 102 and an inner sleeve 104. The outer sleeve 104 has an aspiration port 106 that is in fluid communication with an inner channel 108. The inner sleeve 104 is driven in a reciprocating manner by a motor (not shown). Movement of the inner sleeve 104 cuts tissue 110 that is pulled into the aspiration port 106.

The inner sleeve 104 has a circumferential slit 112 that allows the distal end of the sleeve 104 to bend toward the aspiration port 106 when engaging and cutting the tissue 110. The bending of the inner sleeve 104 assist in cutting the tissue 110.

Figure 7 shows another embodiment of a flexible cutter 120 which has a flexible outer sleeve 122 and a flexible inner sleeve 124. The outer sleeve 122 has an aspiration port 126 that is in fluid communication with an inner channel 128. The outer sleeve 122 is preferably constructed from a flexible plastic or curved metal material that can bend and conform to the shape of a body passage or cavity. The inner sleeve 124 is preferably constructed from a metal material that can cut tissue pulled into the aspiration port 126.

The inner sleeve 124 has a plurality of circumferential slits 130 that reduce the stiffness of the sleeve 124. The slits 130 allow the inner sleeve 124 to follow the shape of the outer sleeve 122. The most distal slit 130 allows the distal end of the inner sleeve 124 to bend into the aspiration port 126 to assist in the cutting of the tissue 110. The flexible cutter 120 can function as a cutting catheter that is inserted into cavities and passages of a body. For example, the flexible cutter 120 can be used

to cut polyps, fibroids and other vascularized human tissue.

Figure 8 shows a cutter 130 coupled to a radio frequency (RF) electrical generator 132. The cutter 130 includes a tip 134 that is connected to a motor (not shown) located within a handpiece 136. The handpiece 136 has an aspiration line 138 that is coupled to a vacuum source (not shown). The handpiece 136 is coupled to the generator 132 by a pair of connectors 140 and 142. One of the connectors 140 provides power to the motor. The other connector 142 supplies electrical energy to the tip 134 so that the surgeon can cauterize tissue with the cutter 130. The electrical energy may be controlled by a foot pedal (not shown) that can be manipulated by the surgeon.

A surgeon can thus both cut and cauterize tissue with the same device. By way of example, the cutter 130 may be used to cut polyps or fibroids in a laparoscopic procedure. The generator 132 may have a plurality of control functions that allow the surgeon to vary the frequency, pulse rate or time duration of electrical energy provided to the cutter 130.

Figure 9 shows the cutter tip 134 constructed as an electrode. The tip 134 has an inner sleeve 144 that reciprocates across an aspiration port 146 within an inner channel 148 of an outer sleeve 150. The tip 134 also has an outer conductive layer 152 that is separated from the outer sleeve 150 by a layer of insulation 154. The outer conductive layer 152 is covered with an layer of insulation 156. The outer sleeve 150 and outer conductive layer 152 are connected to electrical terminals of the generator 132. Electrical

current flows through tissue between the outer sleeve 150 and the outer conductive layer 152.

As an alternate embodiment, the inner sleeve 144 can be connected to the generator 132 instead of the outer sleeve 150. The cutter 130 may then provide pulses of current to the tissue as the inner sleeve 144 reciprocates across the aspiration port 146. The system may also have a voice system which provide input on the present mode of the system. By way of example, the system may provide an audio indication that the electro-cautery function is active, or provide an audio indication that the some component was not set-up or assembled correctly.

Figure 10 is a schematic of a system 160 which controls the motor speed of a motor 162 and a tip 164. In general the system 160 provides more power to the motor 162 with an increase in the load on the tip 164. For example, when the tip 164 engages a more fibrous tissue, the resistance of the tissue will slow down the tip 164 and the motor 162. The system 160 senses the reduction in speed and automatically increases the power to the motor 162.

The motor 162 is preferably a brushless DC motor device which contains three coils that drive an internal rotor (not shown). The system 160 includes a motor controller 166 that provides power to the motor 162. The motor controller 166 preferably provides three sinusoidal drive signals to the coils of the motor 162. The sinusoidal signals provide a relatively smooth control of the motor.

The system 160 has a differential amplifier 168 that senses the input voltage of the motor 162 on line 170 and the output current of the motor

162 on line 172. The output of the differential amplifier provides a feedback control signal to the motor controller 166 on line 174. The system 160 monitors the speed of the motor 162 by sensing the output current. It being understood that the current increases with a decrease in motor speed. The system 160 varies the input voltage to the motor 162 to maintain a constant voltage to current ratio and compensate for different loads on the motor. Although a differential amplifier is shown and described, it is to be understood that the system may control the power provided to the motor as a function of speed in a variety of ways. For example, the motor may contain a Hall sensor that directly measures the speed of the motor and provides a feedback signal that is processed by the motor controller 166 to increase power with a reduction in motor speed.

Figure 11 shows an alternate embodiment of a system 180 which automatically disconnects the cutter 182 from a vacuum source 184 when the cutter 182 is no longer cutting. The system 180 prevents the vacuum source 184 from pulling tissue into the aspiration port of the cutter 182 when the inner sleeve is no longer reciprocating relative to the port. Continued aspiration while the cutter 182 is no longer properly functioning may result in tissue damage.

The system 180 includes a speed (RPM) sensor 186 which senses the speed of the cutter motor. The sensor 186 provide a feedback signal to a controller 188. The controller 188 controls a solenoid actuated on/off valve 190 located between the vacuum source 184 and a vacuum reservoir 192. When the motor speed falls below a threshold level the controller 188 drives the valve 190 to an off

position to terminate the flow of aspiration fluid from the cutter. When the cutting speed increases above the threshold value the controller 188 opens the valve 190 to resume normal operation.

Figure 12 shows a fluid irrigation system 200 that provides irrigation fluid to the patient. In an opthalmolic procedure the irrigation fluid is typically introduced to the cornea through a secondary incision.

The system 200 includes a fluid reservoir 202 that typically provides fluid through the force of gravity to a tip 204 located within the patient. The flow of irrigation fluid from the fluid reservoir 202 to the patient is controlled by a valve 206. The valve 206 may be a solenoid actuated on/off device that is controlled by a foot pedal 208. The foot pedal 208 can be manipulated by the surgeon to control the flow of irrigation fluid to the patient. As an alternate embodiment, the valve 206 may be a proportional device that allows the surgeon to control the amount of irrigation fluid that flows to the patient.

Figure 13 shows a vacuum control system 210 that contains a plurality of vacuum sources 212, 214, 216 and 218 connected in parallel with a vacuum reservoir 220 and a cutter 222. The multiple vacuum sources are actuated sequentially to provide greater flowrate and sensitivity than a single unit system.

The system 210 includes a vacuum transducer 224 that senses the vacuum pressure provided to the cutter 222, and a foot pedal 226 that allows the surgeon to control the vacuum pressure. The output of the transducer 224 and the foot pedal 226 are provided to a differential amplifier 228.

The amplifier 228 provides an error signal that is processed by a controller 230. The controller 230 provides control signals to actuate and control the vacuum sources 212, 214, 216 and 218. In the preferred embodiment, the vacuum sources are variable speed diaphragm vacuum pumps.

In operation, the controller 230 may actuate and drive one of the pumps 212, 214, 216 or 218. The surgeon may request a lower vacuum pressure by depressing the foot pedal 226. Depressing the foot pedal 226 varies the error signal provided by the differential amplifier 228. The controller 230 processes the error signal and actuates, or changes the speed, one or more of the inactive vacuum pumps to decrease the vacuum pressure provided to the cutter 222. Further depressing the foot pedal may induce the actuation of the other pumps and so forth and so on. The controller 230 may also vary the speeds of the pumps 212, 214, 216 and 218 to further obtain a desired vacuum level. As an alternate embodiment, the system may have a plurality of orifices that each have a different diameter. The different orifices can be coupled to one or more pumps.

Figure 14 shows an alternate embodiment of the system shown in Fig 13. The intake and exhaust lines of pump 214 are switched so that the pump provides a positive pressure to the vacuum reservoir 220. The positive pressure source 214 allows the controller 230 to rapidly increase the pressure within the system when the surgeon releases the foot pedal 226. The push-pull dual pump configuration provides a vacuum system with a quick response to commands for increasing or decreasing the vacuum pressure.

Figure 15 is another alternate embodiment of a vacuum system with an electronically controlled pump assembly 240. The pump assembly 240 includes an intake valve 242 and an exhaust valve 244 that control the flow of fluid from a pumping assembly 246. The pump assembly 246 may contain a flexible diaphragm or piston that pumps fluid within an internal pumping chamber of the assembly. The intake valve 242 is open during an intake stroke of the pumping assembly 246 and closed during an exhaust stroke of the assembly 246. Conversely, the exhaust valve 244 is closed during the intake stroke and open during the exhaust stroke.

The valves 242 and 244 are preferably solenoid actuated devices that are driven by the controller 230. The controller 230 can vary the timing on the opening and closing of the valves 242 and 244 to control the flowrate through the pump assembly 246 and the vacuum pressure provided to the cutter 222. As an alternate embodiment, the valves 242 and 244 may be proportional devices that allow the controller 230 to control the flowrate and vacuum pressure of the system.

Figure 16 is a valve 250 that can control the vacuum pressure provided to a cutter 252 from a vacuum source 254 and reservoir 255. The valve 250 includes a core 256 that rotates within a valve housing 258. The core 256 has an inner channel 260 that periodically becomes aligned with an inlet port 262 and an outlet port 264 of the valve housing 258. Fluid flows through the valve 250 when the inner channel 260 is aligned with the ports 262 and 264. The core 256 can be rotated by a motor 266 that is controlled by a controller 268. The motor 266 can vary the rotational speed of the core 256. Varying the core speed changes

the flowrate through the valve 250 and the vacuum pressure provided to the cutter 252. The valve 250 can be utilized in a system that does not control the vacuum pressure by varying the speed of the cutter.

Figure 17 is an alternate embodiment of a variable port cutter 270. The cutter 270 includes an outer sleeve 272 that has an aspiration port 274 in fluid communication with an inner channel 276. An inner sleeve 278 is located within the inner channel 276 of the outer sleeve 272. Mounted to the outer sleeve 272 is a first solenoid 280 and a second solenoid 282. The solenoids 280 and 282 are connected to a controller 284 and coupled to the outer sleeve 272 by a magnetic core 286.

The controller 284 provides a current to one of the solenoids 280 and 282 which creates a electromagnetic force on the inner sleeve 272. The first solenoid 280 is wound to move the inner sleeve 278 toward the aspiration port 274. The second solenoid 282 moves the sleeve 278 away from the port 274. The controller 284 sequentially drives the solenoids 280 and 282 to reciprocate the inner sleeve 278 across the aspiration port 274. The controller 284 can provide control signals to the solenoids 280 and 282 to control how far the inner sleeve 278 moves across the port 274 and the size of the aspiration opening. For example, the controller 284 may control the solenoids so that the inner sleeve 278 moves only half-way across the aspiration port 274. The variation in sleeve movement will change the flowrate within the inner channel 276.

Figure 18 shows a tip 290 which has a bend at the proximal end. When inserted through an

incision to perform an opthomalmic procedure, the bent tip 290 may provide more transverse energy to the eye without damaging the incision. The bent tip 290 may utilize the flexible inner sleeve shown in Fig. 7.

Figure 19 shows an alternate embodiment of a cutter 300 which has an outer sleeve 302 that has a plurality of aspiration ports 304 that are in fluid communication with an inner channel 306. The cutter 300 further has an inner sleeve 308 that is reciprocated by a motor (not shown) to cut tissue pulled into the aspiration ports. The multiple aspiration ports 304 are desirable when removing large amounts of tissue. By way of example, such a cutter 300 would be preferable when performing a liposuction procedure.

Figure 20 shows a transmitter 310 that monitors the location of a cutter 312 placed within tissue 314. The transmitter 310 may provide audio frequency (sonar) waves that are received by the cutter 312. The transmitter 310 and cutter/receiver 312 can be coupled to a computer 316 which processes the transmitted signals to determine the location of the cutter 312 within the tissue 314.

What is claimed is:

1. A surgical cutter, comprising:

an outer sleeve which has an aspiration port that is in fluid communication with an inner channel; and,

an inner sleeve that is located within said inner channel of said outer sleeve, and which has a circumferential slit located at a distal end of said inner sleeve.

2. The surgical cutter as recited in claim 1, wherein said outer sleeve is constructed from a flexible material and said inner sleeve has a plurality of circumferential slits along a longitudinal axis of said inner sleeve.

3. A surgical system, comprising:

a cutter that has a cutting tip; and,

an electrical generator that is electrically coupled to said cutter to provide electrical energy to said cutting tip.

4. The surgical system as recited in claim 3, wherein said cutter includes an outer sleeve that has an aspiration port in fluid communication with an inner channel, and an inner sleeve that moves within said inner channel.

5. The surgical system as recited in claim 4, wherein said cutter includes an outer conductive layer that is separated from said outer sleeve by a layer of insulation, said outer sleeve and said outer conductive layer are electrically connected to said electrical generator.

6. A surgical cutting system, comprising:

a motorized cutter that operates at a motor speed; and,

a control circuit that senses the motor speed and provides power to said motorized cutter at a level that corresponds to the motor speed, wherein more power is provided to said motorized cutter with a decrease in the motor speed.

7. The surgical cutting system as recited in claim 6, wherein said control circuit includes a differential amplifier that senses an output current of said motorized cutter.

8. A surgical cutting system, comprising:

a motorized cutter that operates at a motor speed;

a vacuum source that is coupled to said motorized cutter to create a flow of aspiration fluid from said motorized cutter;

a valve that can be actuated between an on position and an off position to control the flow of aspiration fluid from said motorized cutter; and,

a control circuit that senses the motor speed and drives said valve to the off position when the motor speed falls below a threshold value.

9. An irrigation system for a surgical cutting device, comprising:

a source of irrigation fluid;

a valve that controls a flow of irrigation fluid from said source of irrigation fluid; and,

an input device that controls said valve.

10. The irrigation system as recited in claim 9, wherein said valve can be actuated between an on position and an off position.

11. A vacuum system for a surgical cutting device, comprising:

a cutter;

a first pump that is coupled to said cutter;

a second pump that is coupled to said cutter; and,

a controller that sequentially actuates said first and second pumps.

12. The vacuum system as recited in claim 11, further comprising an input device that is coupled to said controller.

13. The vacuum system as recited in claim 12, further comprising a vacuum reservoir that is connected to said cutter and said first and second pumps.

14. The vacuum system as recited in claim 12, further comprising a vacuum transducer that is coupled to said vacuum reservoir, and a differential amplifier that is coupled to said input device, said vacuum transducer and said controller.

15. The vacuum system as recited in claim 11, wherein said first pump creates a vacuum pressure and said second pump creates a positive pressure.

16. A vacuum system for a surgical cutting device, comprising:

a pumping assembly that creates a flow of fluid;

an intake valve coupled to said pumping assembly;

an exhaust valve coupled to said pumping assembly;

an electrical controller that controls said intake and exhaust valves to control the flow of fluid from said pumping assembly.

17. A vacuum system for a surgical cutting device, comprising:

a vacuum source;

a cutting device;

a valve housing that has an inlet port connected to said cutting device and an outlet port connected to said vacuum source;

a core that rotates within said valve housing, said core contains an inner channel which periodically become aligned with said inlet port and said outlet port; and,

a motor that rotates said core.

18. A surgical cutter, comprising:

an outer sleeve that has an aspiration port in fluid communication with an inner channel;

an inner sleeve that moves within said inner channel of said outer sleeve;

a solenoid assembly that moves said inner sleeve within said inner channel; and,

a controller that drives said solenoid assembly.

19. The surgical cutter as recited in claim 18, wherein said solenoid assembly includes a first solenoid that moves said inner sleeve in a

first direction and a second solenoid that moves said inner sleeve in an opposite second direction.

20. A surgical cutter, comprising:

an outer sleeve that has a plurality of aspiration ports in fluid communication with an inner channel; and,

an inner sleeve that moves within said inner channel of said outer sleeve.

21. A surgical cutter, comprising:

an outer sleeve that has an aspiration port in fluid communication with an inner channel;

an inner sleeve that moves within said inner channel of said outer sleeve;

a transmitter that transmits a signal to said outer sleeve; and,

a computer that processes the transmitted signal to determine a location of said outer sleeve.

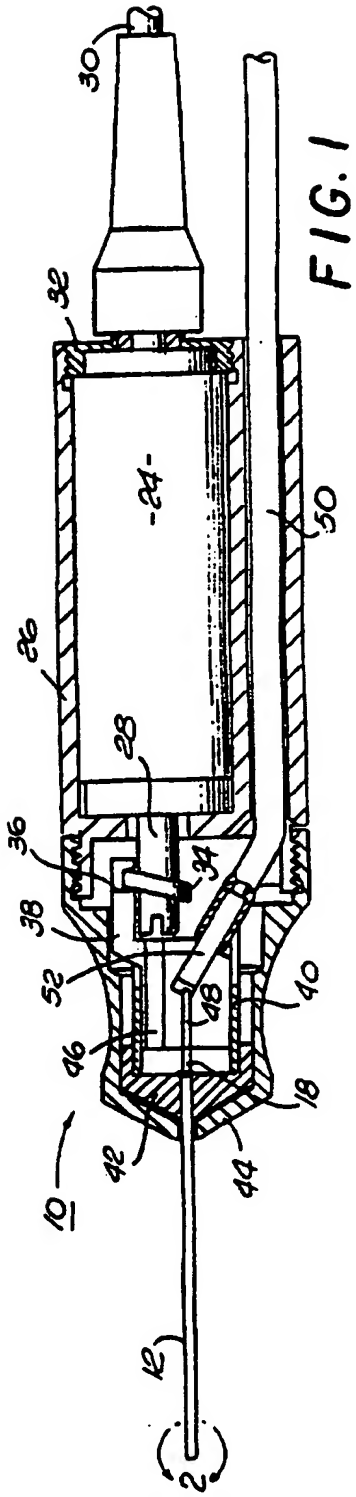


FIG. 1

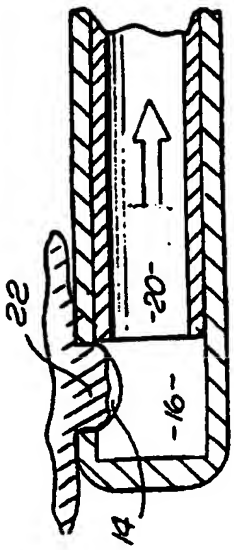


FIG. 3

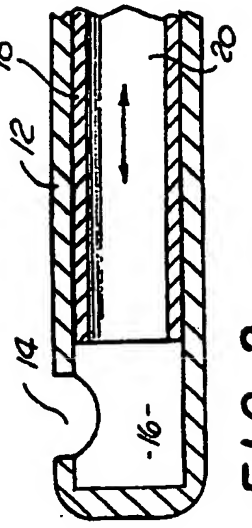


FIG. 2

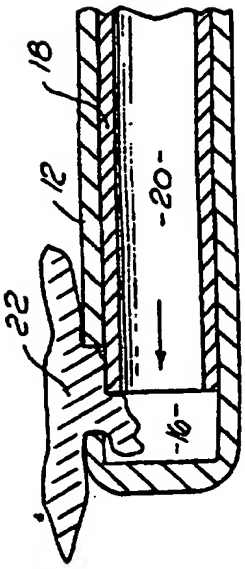


FIG. 4

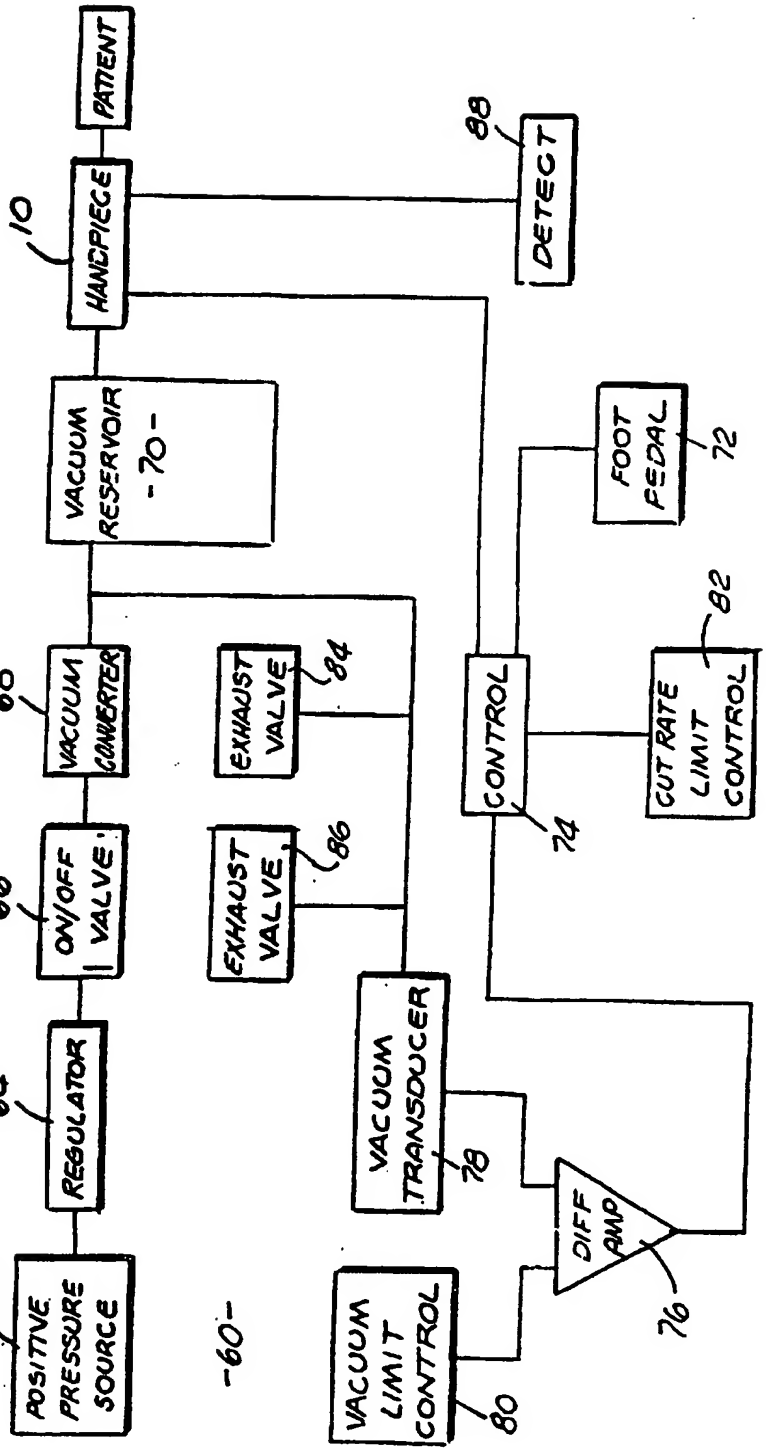

PATIENT
HANDPIECE
10
DETECT
88
VACUUM RESERVOIR
- 70 -
FOOT PEDAL
72
VACUUM CONVERTER
68
EXHAUST VALVE
84
CONTROL
74
CUT RATE LIMIT CONTROL
82
ON/OFF VALVE
66
EXHAUST VALVE
86
REGULATOR
64
VACUUM TRANSDUCER
78
DIFF AMP
76
POSITIVE PRESSURE SOURCE
62
-60-
VACUUM LIMIT CONTROL
80

FIG. 5

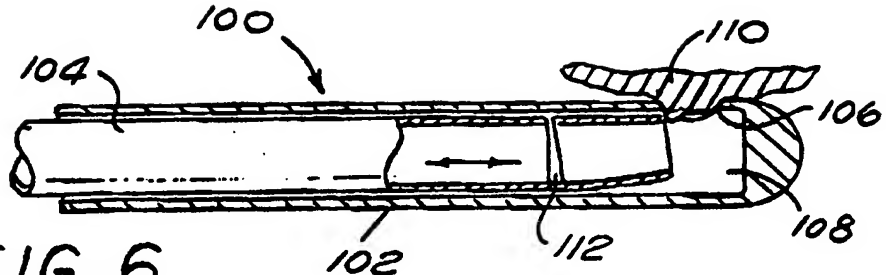


FIG. 6

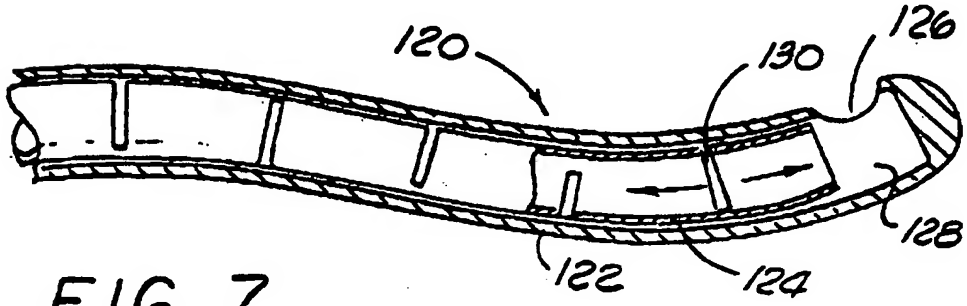


FIG. 7

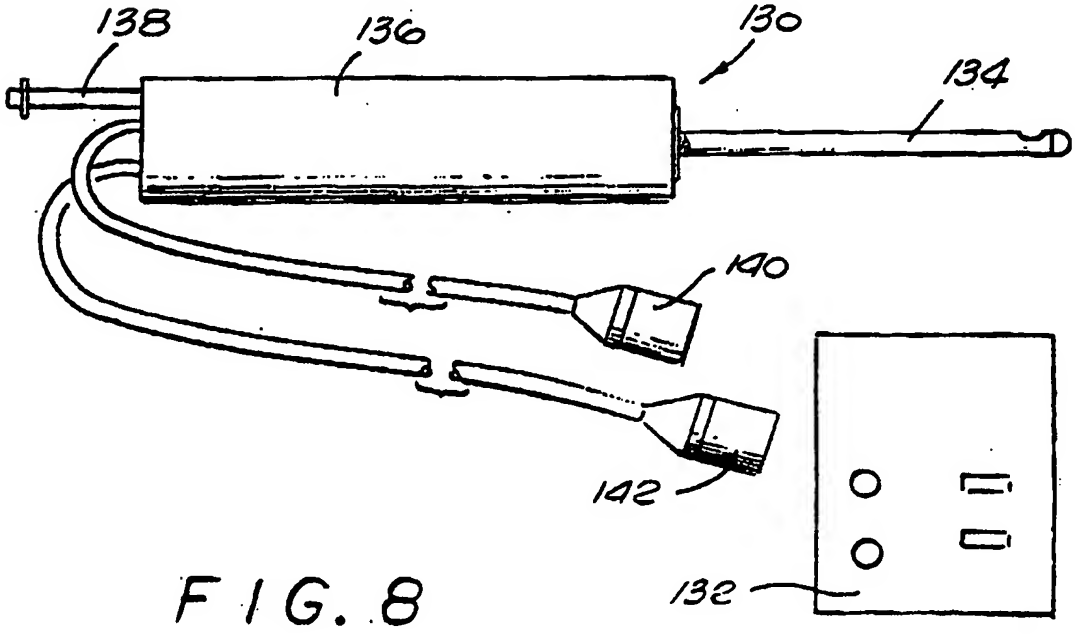


FIG. 8

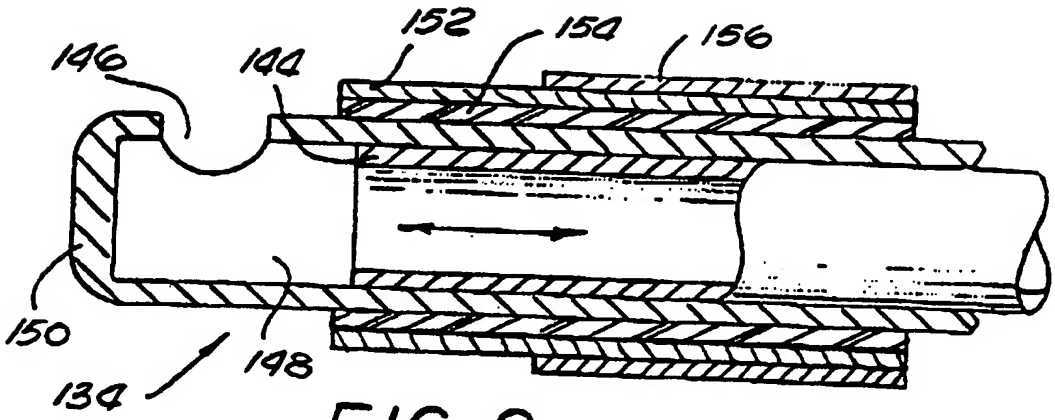


FIG. 9

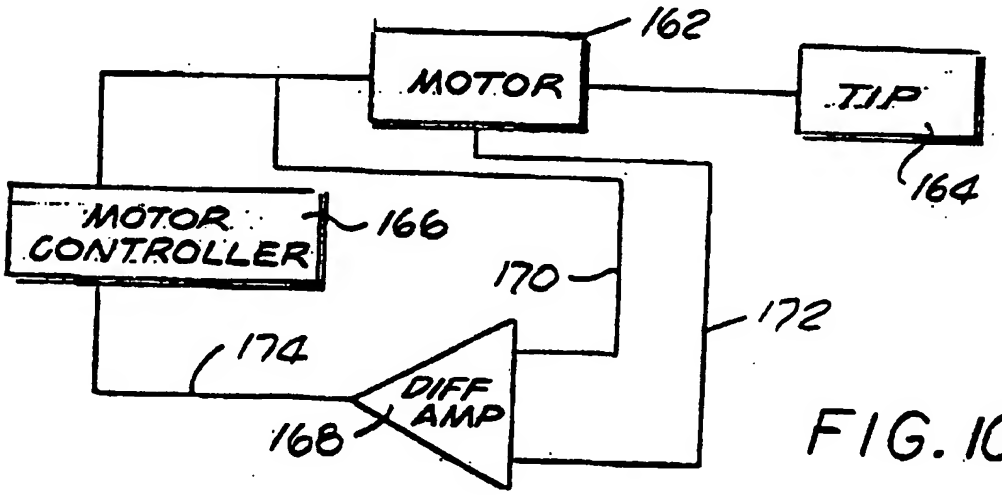


FIG. 10

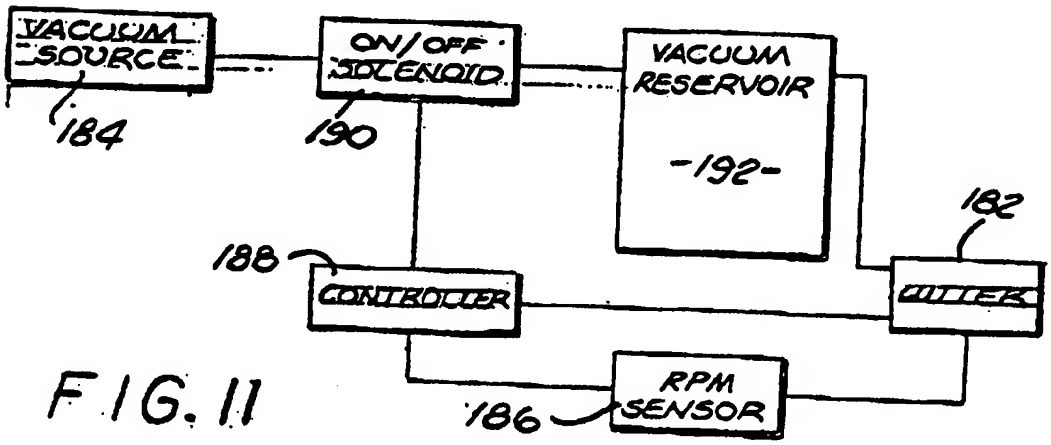


FIG. 11

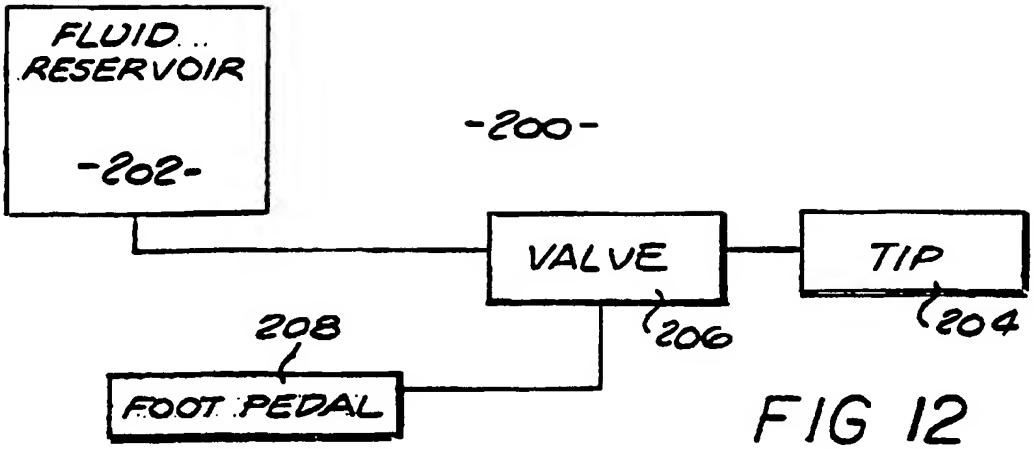
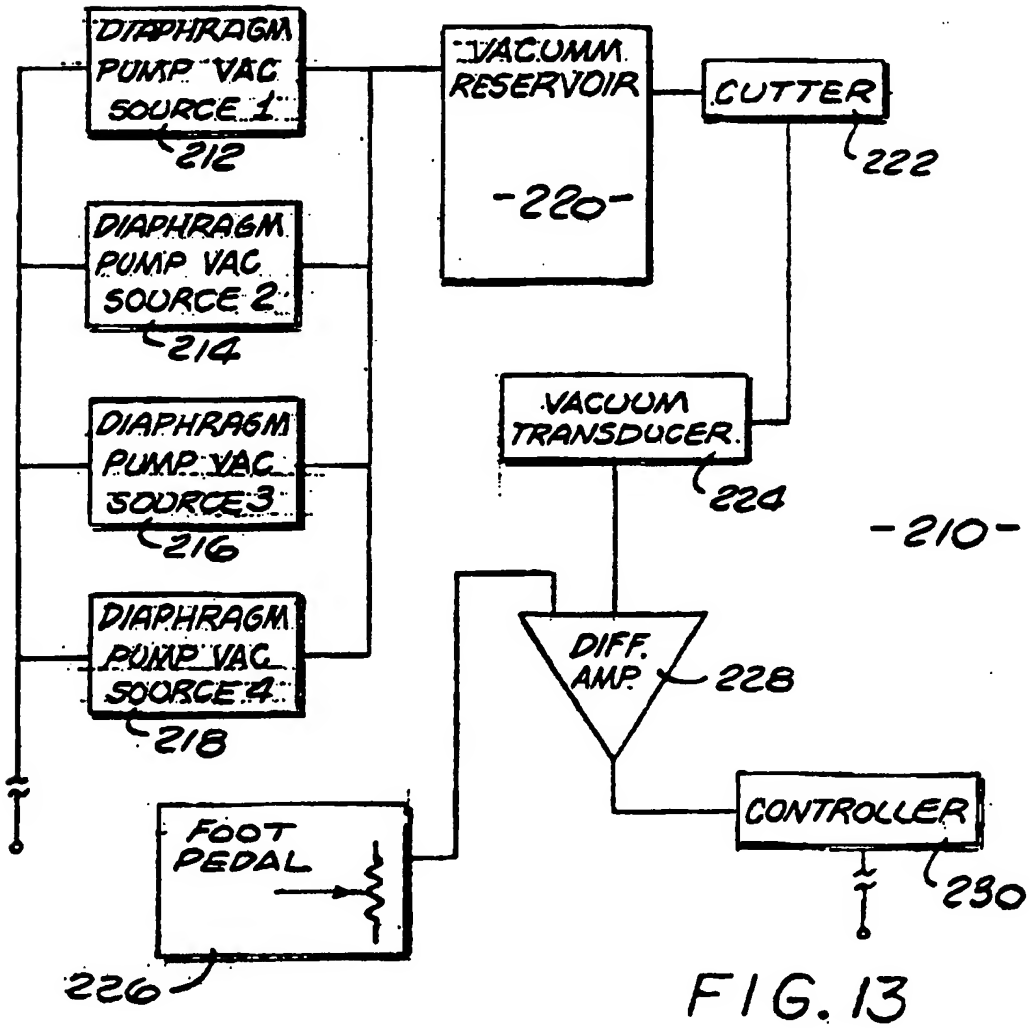

FLUID RESERVOIR
-202-
-200-
VALVE
206
TIP
204
208
FOOT PEDAL

FIG 12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212
DIAPHRAGM PUMP VAC SOURCE 2
214
DIAPHRAGM PUMP VAC SOURCE 3
216
DIAPHRAGM PUMP VAC SOORCE 4
218
VACUMM RESERVOIR
-220-
CUTTER
222
VACUUM TRANSDUCER
224
-210-
DIFF. AMP.
228
CONTROLLER
230
FOOT PEDAL
226

FIG. 13

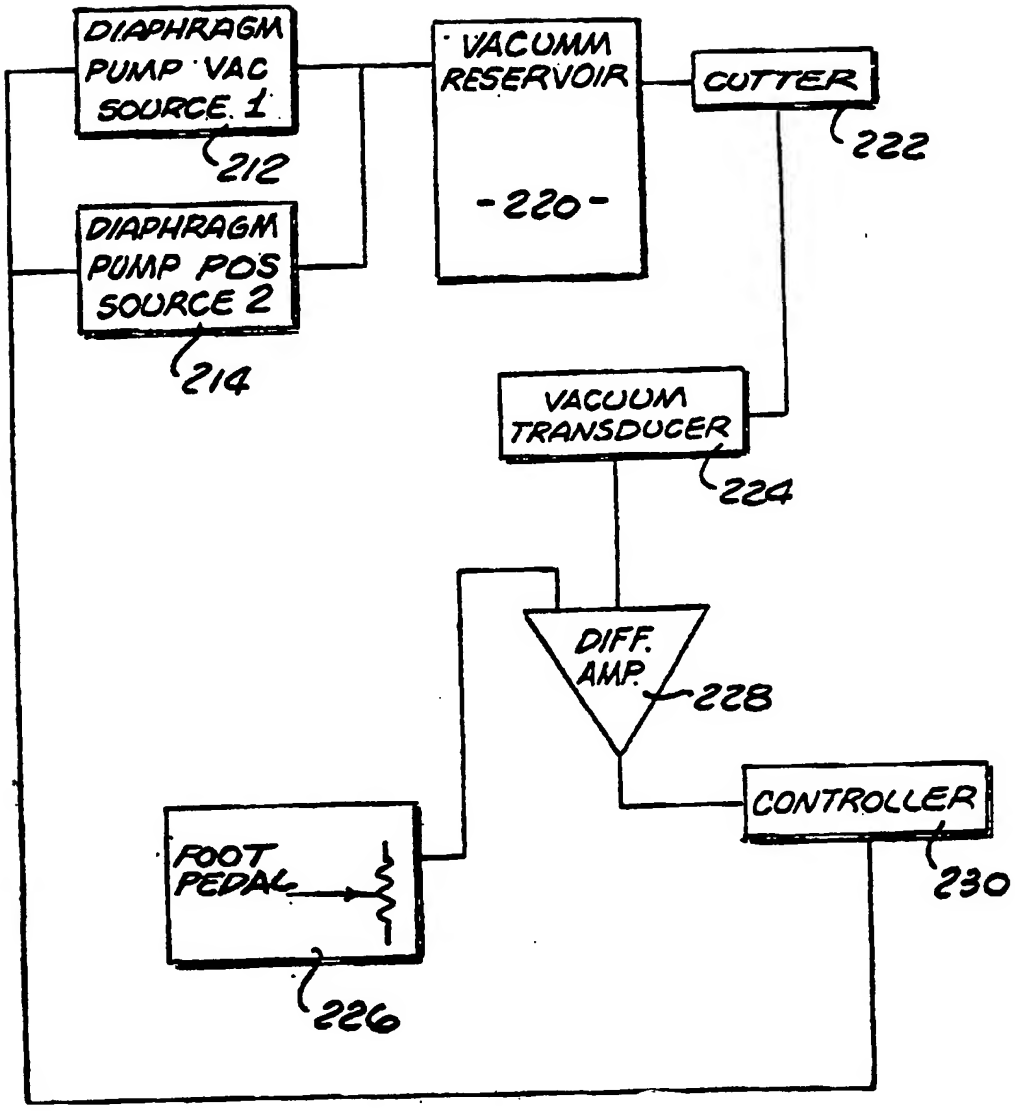
DIAPHRAGM PUMP VAC SOURCE 1
212
DIAPHRAGM PUMP POS SOURCE 2
214
VACUUM RESERVOIR
-220-
CUTTER
222
VACUUM TRANSDUCER
224
DIFF. AMP.
228
CONTROLLER
230
FOOT PEDAL
226

FIG. 14

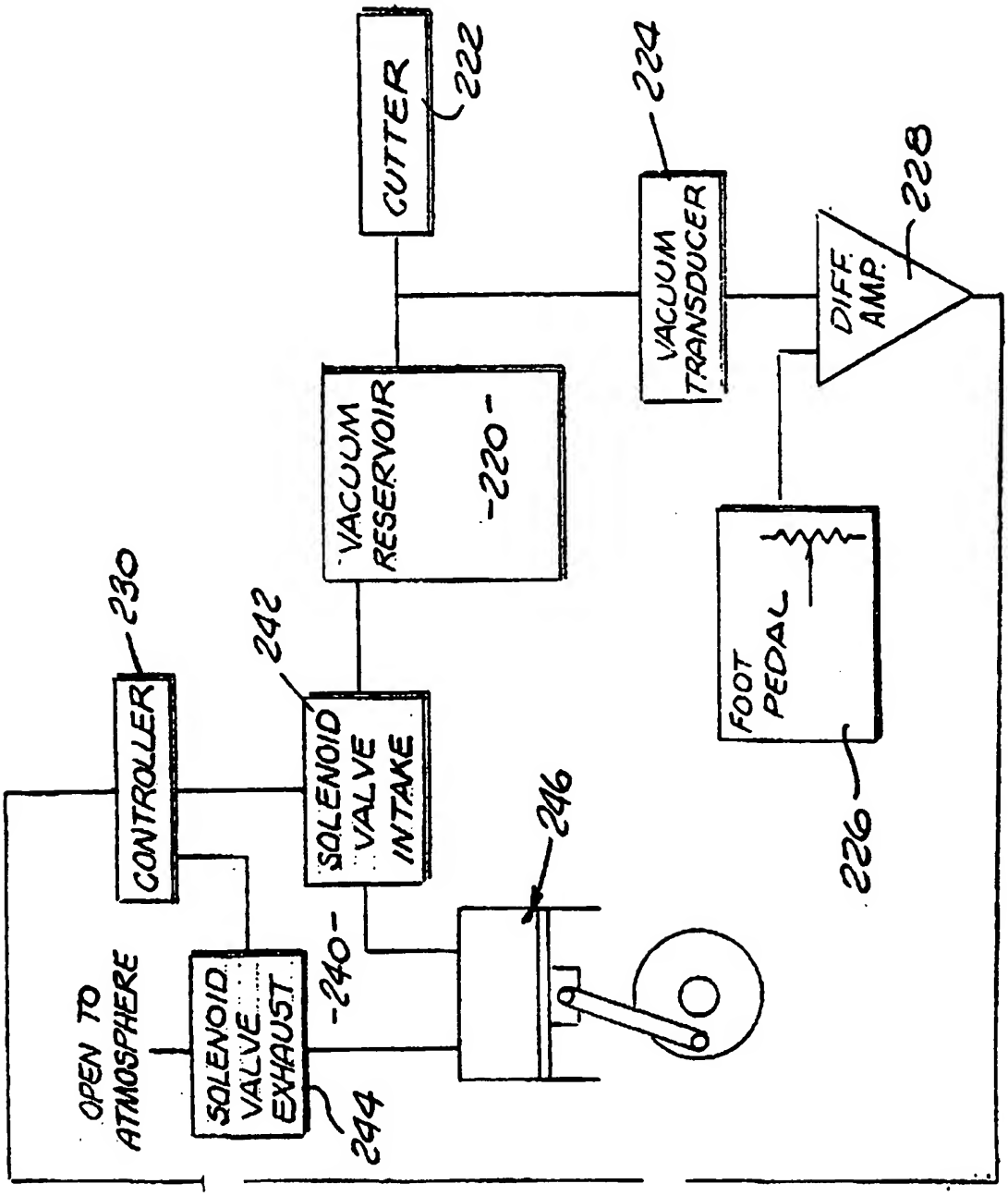
CUTTER
222
224
VACUUM TRANSDUCER
DIFF. AMP.
228
VACUUM RESERVOIR
-220-
FOOT PEDAL
226
230
CONTROLLER
242
SOLENOID VALVE INTAKE
246
-240-
OPEN TO ATMOSPHERE
SOLENOID VALVE EXHAUST
244

FIG. 15

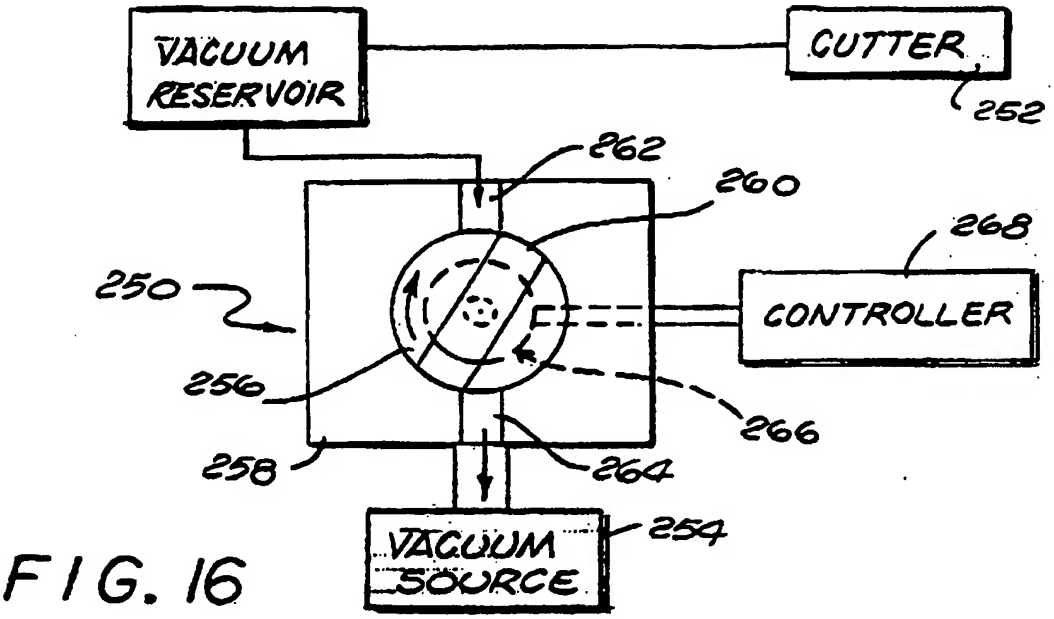

FIG. 16

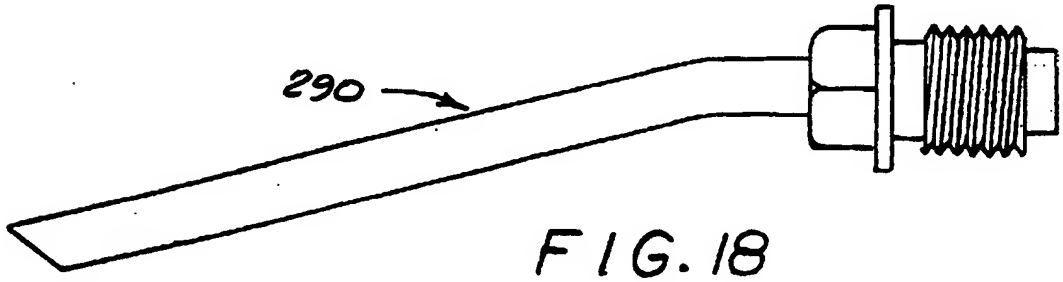

FIG. 18

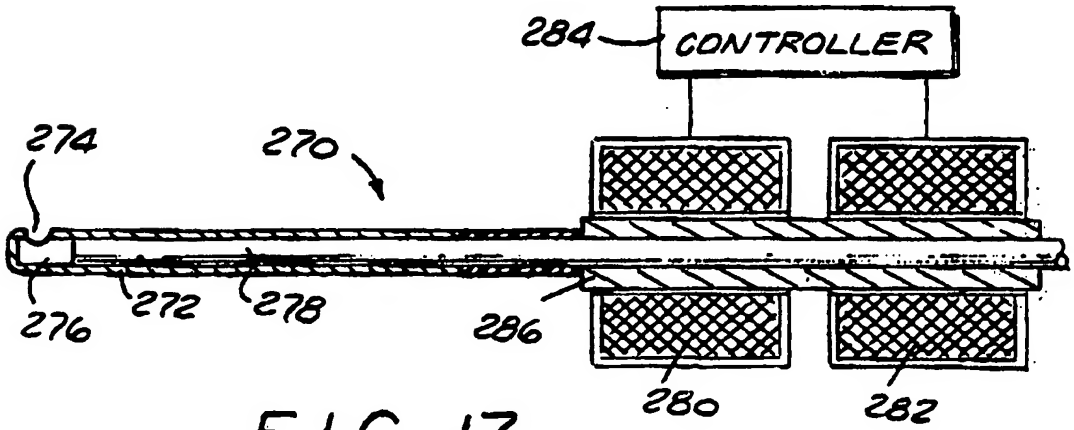

FIG. 17

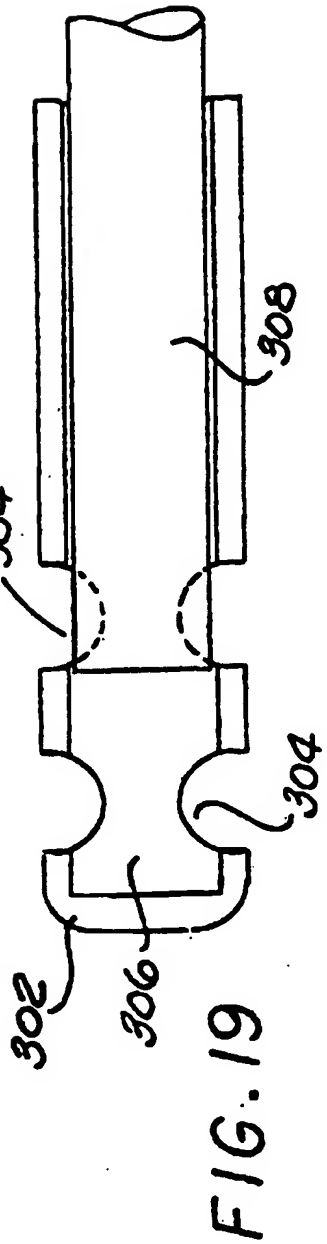

FIG. 19

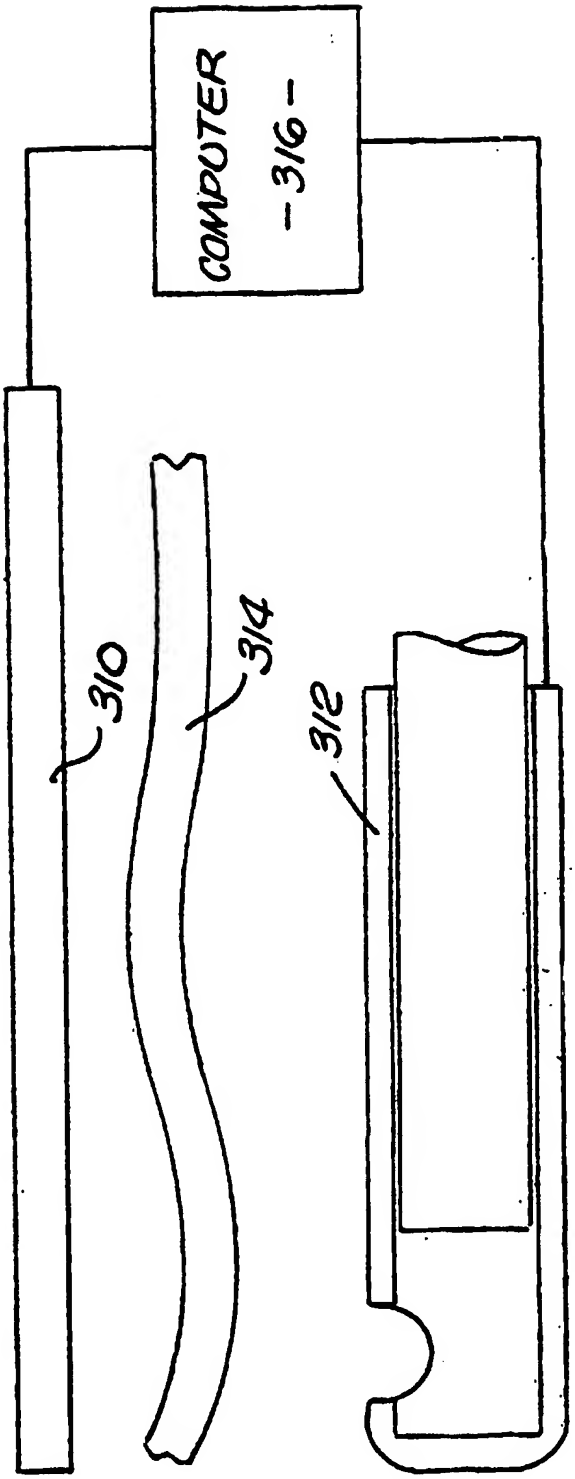

FIG. 20

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/09771

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :A61B 17/32
US CL :604/22; 606/171
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 604/22; 606/170, 171

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,106,364 A (HAYAFUJI et al) 21 April 1992, entire document.	1
Y	US 5,285,795 A (RYAN et al) 15 February 1994, entire document.	2
A	US 5,476,473 A (HECKELE) 19 December 1995, entire document.	1, 2
A	US 5,322,505 A (KRAUSE et al) 21 June 1994, entire document.	1, 2
A	US 5,507,751 A (GOODE et al)) 16 April 1996, entire document.	1, 2

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search	Date of mailing of the international search report
03 OCTOBER 1997	29 OCT 1997
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer MICHAEL THALER
Facsimile No. (703) 305-3230	Telephone No. (703) 308-2981

Form PCT/ISA/210 (second sheet)(July 1992)*

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/09771

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1, 2

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.